COOPERATIVE MISSION CONCEPTS USING BIOMORPHIC EXPLORERS

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Introduction:

Inspired by the immense variety of naturally curious explorers (insects, animals, and birds), their well-integrated biological sensor-processor suites, efficiently packaged in compact but highly dexterous forms, and their complex, intriguing, cooperative behavior, this paper focuses on "Biomorphic Explorers", their defination/classification, their designs, and presents planetary exploration scenarios based on the designs. Judicious blend of bio-inspired concepts and recent advances in micro-air vehicles, microsensors, microinstruments, MEMS, and microprocessors clearly suggests that the time of small, dedicated, low cost explorers that capture some of the key features of biological systems has arrived. Just as even small insects like ants, termites, honey bees etc working cooperatively in colonies can achieve big tasks, the biomorphic explorers hold the potential for obtaining science in-accessible by current large singular exploration platforms.

Biomorphic Explorers:

Biomorphic explorers are small, dedicated, low cost explorers that capture some of the key features of biological systems. These include versatile mobility, adaptive distributed controls and cooperative behavior. Biomorphic explorers offer the potential to obtain significant scientific payoff at a low cost by utilizing the power of a large number of cooperatively functioning units. This is analogous to the approach seen in insect societies. Cooperative behaviors with such biomorphic explorers will be utilized in aspects of missions that are inherently distributed in space, time, or functionality. The advantages of distributed, cooperative exploration include increased reliability and robustness (through redundancy), decreased task completion time (through parallelism), and decreased cost (through simpler individual explorer design). A classification of these explorers based on their mobility ambient/environment divides them broadly into biomorphic flight systems and biomorphic surface/subsurface systems. Another classification is based on size/volume envelope/mass. Three general overlapping categories: 'A' = 1 to 20 cc, < 20g, 'B' = 10 to 200 cc, < 200g, 'C' = 100 to 2000 cc, < 2000g are defined. Example candidates in each category will be presented. Such biomorphic explorers can potentially enable new capabilities in cooperative mission scenarios along with orbiters, landers, rovers, and/or balloons. Particular focus of the mission concepts described in this paper are the biomorphic flight systems in the size B regime namely biomorphic gliders, seedwing flyers and powered flyers. The seed wing pod from the plantworld (illustrated in figure 1a) has inspired a seed wing flyer design shown in figure 1b. which holds promise for a more robust and compact alternative to the parachute for small payloads The cooperative behaviors of bees and other creatures, in combination with the flight modes of birds and soaring birds, have lead to ideas for adaptive biomorphic gliders and biomorphic powered flyers (shown in figure 1c and 1d). Soaring birds (e.g., frigate bird, albatross, and hawks) use wind currents to stay aloft for hours or even days using little power to search for food or travel great distances. Biomorphic flyer concepts can be envisioned to take advantage of the same kinds of rising air currents on certain planets/planet satellites to stay aloft for great periods of time to conduct meteorological and geological surveys. Gliders using this type of natural flight mechanism have greater mobility than balloons, are much lower in mass (and higher in payload fraction than balloons or powered air vehicles), and in suitable atmospheric condition can stay aloft longer than powered craft. Deployed in large numbers these flight systems can substantially enhance science return.). Biomorphic flight systems, thus have the potential for substantially higher mobility (in speed, range, and terrain independence). As an example a Biomorphic Glider baseline design provides a combination of low mass <100 g, high payload fraction > 50% and large terrain coverage of 50-100 Km in 10 minutes. Biomorphic flight systems can even be made to deliver instrument payload/other biomorphic explorers to target sites, greatly extending the utility of those explorers. Cooperative exploration with a orbiter, lander/ballon, a rover, and a multitude of inexpensive biomorphic explorers would allow comprehensive exploration at a low cost and with broad spatial coverage. For orbiters, landers, rovers, and manned missions, flight systems in particular provide a means for exploring beyond the visual range of on-board cameras. They aid in identifying targets of scientific interest and to determine optimal pathways to those targets. The biomorphic flight system itself can be designed to seek out features of interest, crash at the target site, and then act as a homing beacon for further experiments. An important application is to use them as scouts in future planetary exploration where they would look for samples/sites of interest from locations inaccessible to date.

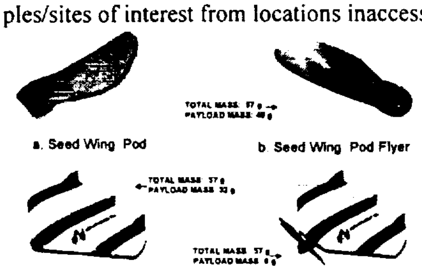

Figure 1: Biomorphic Flight System Examples

Mission Concepts:

The mission concepts to be described are targeted towards the following key objectives: (1)Atmospheric Info Gathering: Distributed Multiple Site Measurements, (2) Close-Up Imaging, Exobiology Site Selection, (3) Deploy Payload: Instruments/Crawlersand (4) Sample Return Reconnaissance Mission Figure 2 illustrates the Biomorphic mission concepts. Specifically the mission concepts are of two types

Figure 2: Typical Biomorphic Mission Concept

Type 1: Probe Deploy of Biomorphic Flight Systems
After orbiting a planet or satellite and sending images to Earth for several weeks, the science team identifies several regions of meteorological/geological interest. One of three entry vehicles is launched from the orbiter so that the payload is released at an altitude of about 15 km over a target area. The entry vehicle contains 100 or so biomorphic flight systems particularly biomorphic gliders that are released. As the first science objective, they perform in-flight atmospheric measurements of pressure, temperature, solar irradiance,atmospheric turbulence spectra, and wind etc as they glide down in a sample cone defined by 10Km high and 100Km Diameter circle around the point of release. Such missions are ideal to address mesoscale meteorology targeting the cluster of gliders to an area ~ 100 sq Km that is diverse. Ephemeral phenomenon such as dust storms could be measured by timing the periodic release of glider clusters over the dust storm season. Distributed measurements, collecting data from the near surface environment and boundry layer will enable validation and prediction of global circulation models.

The second science objective is to obtain close-up imaging, particularly at lower altitudes (1 m and below) providing an unique perspective, higher resolution than possible from orbit, access to rugged terrain not possible with rover. A camera payload of < 15 g is designed looking foreward and down 30 degree to minimize smear and view the landing site in successive nested frames to obtain spatial resolutions of down to 0.5 cm.

The third science objective is to deploy a variety of surface payloads including instruments, in-situ experiments, other biomorphic surface/subsurface systems. Long term distributed surface observations such as seismic measurements(accelerometers), atmospheric pressure (pressure transducer), temperature (thermistor), solar irradiance (solar cell), or a near IR sensor to help differentiate water ice clouds from dust clouds could be achieved by providing additional solar cells on the glider wings for continued diurnal power.

Type 2: Lander Deploy of Biomorphic Flight Systems for Sample Return Reconnaissance Mission
The mission objective is to image over the horizon terrain and perform surface measurements for site selection and sample return reconnaissance. Specific objective includes, to obtain samples from potential exobiology sites and areas of geological interest on Mars. Valles Marineris on Mars is a potentially favored landing site because, by comparison with our Grand Canyon here on Earth, it is expected to be potentially rich in geological units in one single site. Lucchita et al [1] has described Valles Marineris as an optimum science sample site. A lander equipped with a large rover (and ascent vehicle) lands in the Valles Marineris roughly 10-100 km from an area of potential exobiological significance, fault zones with exposed geological features, and eroded canyon walls with exposed sedimentary layers. The lander is targeted in a relatively flat area (devoid of interesting samples) to minimize risk in landing. The rover is designed for traversing rugged terrain and is equipped with an arsenal of scientific experiments including the ability to obtain and store samples. Unfortunately, the rover is expected to have a limited life, and there is always a risk of damage or loss in negotiating the rugged terrain. Therefore, some knowledge of the terrain and locations of scientific targets can significantly reduce mission risk and improve sample collection efficiency. After shedding the protective gear and making necessary deployments, a javelin is launched from the lander, and lands ~ 500m –1Km away. The javelin and lander begin emitting low-power RF signals, which will be used for radio navigation by the biomorphic flyers and other explorers. The canyons in the foothills of the Valles Marineris are varied, some with steep walls and rubble at the base; others are filled with wind-blown sands. Many canyons end abruptly after a short distance or become impassable due to rockslides. From its vantage point in the valley, the lander cannot determine the location of ideal science targets or the best paths to reach them. The rover could waste a tremendous amount of time searching for a suitable path and going down dead ends.

The lander is equipped with several biomorphic flyers. A mechanical spring is used to launch the flyer specifying a flight heading. The flyer relays imagery to the lander and after landing conducts/deploys a surface experiment and acts as a radio beacon to indicate the selected site.

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Reference (1) Lucchitta, B.K., and Rosanova, C.E., (1998), Valles Marineris 2001 Landing Site Workshop, January 25-26, 1998, Ames National Laboratory, California.